Verification of Translation

17th July 2008

To whom it may concern

Re: German Patent Application No. DE 10329506.2
<u>Daimler Chrysler AG</u>

I, the undersigned, hereby declare that this is a true and faithful English translation of the German document specified above.

Theresa G.L. White, MIL, AITI

FEDERAL REPUBLIC OF GERMANY

Priority Certificate of the Submission
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Title:	Self-igniting internal combustion engine
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The attached is a true and faithful copy of the original documents appertaining to this patent application.

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Self-igniting internal combustion engine

The invention concerns a method for operating an internal combustion engine according to Claim 1, in particular a diesel combustion engine, and an injection device according to Claim 15.

In the operation of internal combustion engines with direct fuel injection it is attempted to influence the combustion and the generation of emissions by varying the injection process. In direct injection combustion engines with self-ignition, in order to achieve load-dependent fuel injection, injection valves which control the injection process by virtue of an appropriate valve structure and by correctly timed opening of the valves are used. This also improves and optimises the functional efficiency of a downstream exhaust gas treatment unit. For example, a suitable injection process design can serve to produce an exhaust gas of below stoichiometric composition for the desulphatisation of NO_x storage catalysers and for the on-board generation of NH_3.

From a previously unpublished patent application with the official file number DE 101 594 79.8-13 a process is known in which fuel is introduced into a combustion chamber in the form of a main injection and an after-injection such that both

injections can be made in a pulsed manner. The intention here is to influence the duration of combustion so as to modify the time sequence of torque variation or pressure variation in the cylinder of the combustion engine in order to influence the composition and temperature of the exhaust gas.

From DE 199 539 32 A1 a method is known in which it is proposed to operate a combustion engine in a combined homogeneous/heterogeneous mode in order to deliver medium and higher powers. In this method an injection strategy is used to permit both an early, homogeneous mixture to form during the compression stroke and a subsequent, heterogeneous mixture to form at around top-dead-centre, fuel injection during the homogeneous mixture formation taking place at a lower injection pressure than during the heterogeneous mixture formation in order to avoid deposition of fuel on the cold walls of the combustion chamber. It has been shown, however, that despite the measures proposed above, high exhaust gas emissions still occur. It is therefore necessary to adopt additional measures in order to minimise exhaust emissions.

The purpose of the present invention is to create a method for operating an internal combustion engine with self-ignition by means of which exhaust gas emissions are reduced. According to the invention this is achieved by the characterising features of Claim 1.

A further aim of the invention is to provide a device by means of which a self-igniting combustion internal engine is improved in relation to its exhaust gas behaviour and its fuel consumption. According to the invention this aim is achieved by a device having the characteristics of Claim 15.

According to the method of the invention fuel is injected directly into a combustion chamber of an internal combustion engine in the form of a plurality of fuel jets by means of an injection nozzle with injection holes comprising a nozzle needle, a quantity of fuel being injected as a pulsed after-injection at a time later than the main injection, the after-injection being effected in pulsed part-quantities such that the fuel part-quantities of the after-injection are of different sizes. This enables a controlled adaptation of the fuel part-quantities to the position of the piston in the cylinder and/or to an operating point of the combustion engine so that the respective part-quantities are mixed with combustion air in good time before reaching the cylinder wall and wetting of the cylinder wall with fuel is therefore largely avoided.

According to an embodiment of the invention, during the pulsed after-injection a stroke of the nozzle needle of the injection nozzle and/or a fuel injection pressure are adjusted in such manner that when each part-quantity of the after-injection is injected into the combustion chamber the range of the respective fuel jet in the combustion chamber is limited such that said range is smaller than the distance to a combustion chamber boundary. This minimises fuel deposition in the cylinder of the type which, for example, increases steadily when the gas pressure and temperature in the cylinder are low. According to the invention the injection jet is broken up and vaporised more effectively. According to the invention the pulsed after-injection reduces the length of the liquid jet, namely the length or penetration depth of an injection jet consisting of liquid fuel. This avoids deposition of the fuel on the cold combustion chamber walls since this fraction of

the fuel will mostly react with the residual air and gas in the cylinder and will therefore not pass into the engine oil as in the case with elevated fuel deposition.

According to a further embodiment of the invention a first fuel part-quantity of the after-injection is made to be larger than a subsequent fuel part-quantity of the after-injection. This acts against a locally pronounced enrichment of the mixture formed in the combustion chamber particularly during the pulsed after-injection so that soot particle formation is minimised or prevented particularly during the after-injection. It is expedient to adjust the individual amounts injected during the after-injection in such manner that in each case a defined amount of fuel enters the combustion chamber and undergoes intensive and complete mixing with the combustion air before the fuel jet has reached the boundary of the combustion chamber or a cylinder wall.

In accordance with another embodiment of the invention the after-injection is effected into the combustion chamber at an injection pressure lower than that of the main injection. This helps to avoid further fuel deposition on the walls since during the after-injection the combustion chamber counter-pressure decreases progressively as the piston position changes. Furthermore, the pressure of the fuel injected during the pulsed after-injection can be varied or adapted continuously, preferably as a function of the piston position, or decreased to a level lower than during the main injection, to counteract the falling combustion chamber pressure during an expansion stroke of the combustion engine. In this way, for example, the penetration depth of the fuel part-quantities in

the form of injection jets can be kept constant in the combustion chamber during the pulsed after-injection.

In another embodiment of the invention a stroke of the nozzle needle of the injection nozzle is adjusted so as to produce an unstable cavitating flow in the injection holes of the injection nozzle. This is intended to cause the fuel droplets in the injected jet to disintegrate shortly after emerging from the injection nozzle and to be atomised promptly. This largely minimises the impact of the fuel against the cylinder walls that serve as the boundary of the combustion chamber, for example.

According to the present invention the pulsing of the after-injection takes place in such a manner that the range of the fuel jet produced by each part-quantity injected into the combustion chamber is limited. This largely limits the range to a value somewhat smaller than the distance to a cylinder wall by promoting the disintegration of the fuel jets injected into the combustion chamber. During the after-injection the individual injection pulses are controlled such that the jet pulses are adapted to the individual injections, and at the compression level of the gas in the combustion chamber the range of the fuel jets is approximately equal to the distance to the cylinder wall on the combustion chamber side or to the piston end. An injection jet pulse and an injected part-quantity are preferably controlled by pulse duration and timing in combination with an appropriate injection nozzle needle design so that the fuel jets disintegrate with increased atomisation shortly after emerging from the nozzle. Soot particle formation and significant fuel deposition on the cylinder wall are largely avoided or minimised.

Other criteria for the design of an additional after-injection are indicated by the requirements for possible exhaust gas after-treatment measures.

To implement the method according to the invention, a nozzle needle is proposed that opens inwards and has a plurality of injection holes, and by means of which the fuel is injected through the injection holes into the combustion chamber in the form of fuel jets such that an injection hole cone angle of between 80° and 140° or 80° and 160° can be set between the injected fuel jets.

In a version of the method according to the invention the stroke of the nozzle needle can be set in an opening direction so that during the pulsed after-injection the stroke of the nozzle needle can be adjusted variably. If so desired, this stroke adjustment can be carried out in a load-dependent manner. This varies the part-quantity injected during the pulsed after-injection. In addition, adjustment of the stroke can produce an unstable, cavitating flow in the injection holes of the injection nozzle.

Other advantages are detailed in the description of the drawings given below. The drawing illustrates exemplary embodiments of the invention. The description and claims contain numerous characteristic features in combination. A person skilled in the art will also be in a position to consider these features individually, as appropriate, and bring them together in other combinations.

Fig. 1 shows a schematic cross-section through an internal combustion engine with self-ignition.

Fig. 2 shows a diagram of the course of a fuel injection process with a 5-pulse pre-injection, a main injection and a 5-pulse after-injection.

Fig. 3 shows a diagram of the course of a fuel injection process with a 5-pulse pre-injection with constant pulse duration at constant need stroke and increasing injection pressure during pre-injection, a main injection and a 5-pulse after-injection with decreasing injection pressure and constant pulse duration at constant needle stroke.

Fig. 4 shows a diagram of the course of a fuel injection process with a 4-pulse pre-injection with increasing pulse duration at constant injection pressure, a main injection and a 4-pulse after-injection at constant injection pressure with decreasing pulse duration.

Fig. 5 shows a diagram of the course of a fuel injection process with a block pre-injection at constant injection pressure, a main injection and a block after-injection at constant injection pressure.

Fig. 6 shows a schematic view of the effect of an unstable cavitating flow in the nozzle hole of a multi-hole nozzle.

Fig. 1 shows an internal combustion engine 1 in which a crankshaft 2 is driven via a piston rod 4 by a piston 5 moving in a cylinder 9. Between the piston 5 and a cylinder head 10 the cylinder 9 contains a combustion chamber 8 which includes a piston recess 6 formed in the piston end 7.

When a crank 3 of the crankshaft 2 rotates clockwise on a crank circle 11, the combustion chamber 8 becomes smaller and the air it encloses is compressed. The charge change in the combustion chamber 8 is effected by means of gas exchange valves and gas ducts (not shown) in the cylinder head 10.

When the crank 3 reaches top dead centre, hereinafter referred to as TDC, the compression stroke is complete. The current position of the piston 5 relative to the cylinder head 10 is determined by the crank angle φ relative to TDC 12.

An injection nozzle 13 with a plurality of injection holes is arranged centrally in the cylinder head 10. The injection holes are all inclined at an angle of 40° to 80° to the nozzle axis. The injection hole cone angle is approximately 80° to 160°. In principle, the nozzle can be a conventional and therefore inexpensive hole nozzle of the seating-hole, mini blind hole or blind hole type. The injection nozzle 13 is controlled by an electronic control unit 16, the engine control system, via a signal line 15 and an actuator 14, for example a piezo-actuator. The injection jets emerging from the injection nozzle are denoted by reference numeral 17.

The fuel is supplied by an injection pump 18 in a plurality of pressure steps and a control valve 20, expediently an electronically controlled solenoid valve, limits the maximum

pressure in the fuel line 19. The injection pressure is preferably adapted by means of a suitable injection system. A needle-stroke-controlled injection system with corresponding pressure modulation can be used for this purpose.

According to the invention, the injection nozzle 13 has four to fourteen injection holes which are preferably distributed in one or two rows of holes around the periphery. The operation of the combustion engine 1 can be optimised by the optional use of an injection nozzle with two rows of holes that can be controlled in different manners, for example by an inward-opening coaxial variable nozzle. One of the two rows of holes rows can preferably be actuated with an injection hole cone angle α, preferably between 130° and 160°, to give conventional lean operation, while the second row of holes with a substantially smaller injection hole cone angle, preferably between 80° and 140°, can be used in particular to produce rich combustion with an after-injection and where necessary for a pre-injection. By actuating the row of holes with the smaller injection hole cone angle α, for example 80° instead of 150°, a free jet length is extended in a subsequent after-injection, at 70° CA to 90° CA after TDC, for example. Thus the fuel jet 17 does not impinge on the cylinder wall but is directed towards the piston recess 6 or at end 7 of the piston.

The injection nozzle 13 has a nozzle needle 13a illustrated in Fig. 6 which is connected to a control element (not shown). When the nozzle needle 13a is actuated by said control element, it is moved so as to open or close the injection nozzle 13. In this arrangement a defined operating stroke h is set during operation adjustment dependent on operating

point and/or as a function of the crank angle φ. The fuel throughput can then be determined or varied as a function of the operating stroke h, the opening time or pulse duration or the fuel injection pressure set.

The method described here is particularly appropriate for a combined homogeneous/heterogeneous combustion process with self-ignition in order that conventional lean combustion, as known from diesel engines, and rich combustion to optimise a downstream exhaust gas after-treatment unit particularly designed for lean-operated internal combustion engines can be carried out.

The combustion engine 1 also has an exhaust gas purification unit (not shown) with for example a plurality of catalyser units. The self-igniting combustion engine 1 is usually operated largely in lean mode and when necessary, to optimise the downstream exhaust gas purification unit, in rich mode. Lean mode is defined as above-stoichiometric engine operation in which there is excess oxygen during combustion, i.e. $\lambda<1$. Rich mode means below-stoichiometric engine operation in which there is excess fuel during combustion, i.e. $\lambda>1$. Correspondingly, a lean exhaust gas composition means that there is excess oxygen in the exhaust gas and a rich exhaust gas composition means that the exhaust gas is short of oxygen.

With a rich exhaust gas composition, ammonia can be produced from corresponding exhaust gas constituents by means of a first catalyser unit. A second catalyser unit, which adsorbs the ammonia produced by the first catalyser when the exhaust gas composition is rich, releases the ammonia when the exhaust gas composition is lean, and this then serves as the reducing

agent for a reduction reaction in which nitrogen oxides present in the exhaust gas are converted to nitrogen, while at the same time the ammonia is oxidised to nitrogen. As soon as the intermediately stored amount of ammonia has been used up in lean operation, the mode is changed to rich operation. For NO_x regeneration and the desulphatisation of NO_x, storage catalysers and for the on-board production of NH_3 to regenerate a SCR catalyser, it is necessary for the engine to produce a below-stoichiometric exhaust gas which passes into the catalysers, for example the NO_x storage catalyser and/or the SCR catalyser.

During the operation of the internal combustion engine 1 measures are adopted to avoid the deposition of liquid fuel in combination with an after-injection NE carried out after a main injection HE or with a pre-injection VE carried out before said main injection HE, so that early mixing with the combustion air present in the combustion chamber takes place. These measures can be adopted individually or combined with one another so that any conceivable combination of said measures can be chosen according to need.

During both lean and rich operation of the combustion engine 1 the quantity of fuel to be supplied can be introduced into the combustion chamber in the form of pre-, main- and after-injection quantities. The present invention is intended above all to optimise the various fuel quantities and their adaptation dependent on with operating point in order to avoid deposition of fuel on the walls of the combustion chamber.

In the present combustion engine a below-stoichiometric exhaust gas is produced by the after-injection and at least

part of the amount of fuel introduced at a late stage is not therefore involved in the combustion process. Fundamentally, there are several ways of producing a below-stoichiometric exhaust gas. It can be done, for example, by throttling down the engine on the air and exhaust side, or by increasing an exhaust return rate and increasing the fuel quantity in the cylinder or in the exhaust line under neutral load. Compared with throttling down the engine and increasing the exhaust return rate, the fuel-related measure by means of an appropriate after-injection has clear advantages in relation to rapid implementation of the rich operation mode. In this way the size of the part-quantities formed during a pulsed after-injection can be varied from one active phase to the next. Introduction of the fuel inside the engine, compared with the controlled addition of fuel downstream of the engine, has advantages in particular in relation to the precision or necessary accuracy in the production of the exhaust gas constituents needed for the exhaust gas after-treatment system, CO and H_2 in the case of an adsorption catalyser and NH_3 in the case of an SCR catalyser of comparatively low cost.

The injection strategy represented in Fig. 2 envisages a pre-injection, a main injection and an after-injection. The pre-injection VE takes place as a homogenising injection in a range between 140° CA and 40° CA before TDC. This pre-injection VE is carried out at an injection pressure P_1 as a pulsed fuel injection. The pulsing is carried out with a different needle stroke h set for each pulse. This controlled pulsing of the pre-injection VE ensures homogenisation of the part-quantities injected. As an alternative to pulsed pre-injection, homogenisation during the compression stroke can also be produced by cavitation effects in the nozzle blind-

hole area and in the nozzle holes, with constant positioning of the nozzle needle 13a of the injection nozzle 13 by means of direct control via a piezo-control element, for example.

The main injection then takes place at a higher injection pressure P_2 in a range between 10° CA before TDC and 20° CA after TDC. During the main injection HE a larger needle stroke h is set than during the pre-injection VE. The main injection HE is preferably effected 5° CA to 15° CA from the ignition point of homogeneous combustion, at the highest possible injection pressure P_2. The position of the main injection HE is restricted by the maximum permissible peak pressure of the internal combustion engine and the maximum permissible pressure rise of the engine. To avoid a torque increase due to the main injection HE in combination with the previous pre-injection VE and the after-injection NE, the quantity injected in the main injection is reduced appropriately such that the engine torque overall corresponds to the torque during purely lean operation.

The injection of an additional quantity of fuel in the form of the after-injection takes place in particular during the rich phase by means of a 2- to 8-pulse injection in the expansion stroke during an interval of about 20° to 150° CA after TDC. In terms of duration, injection pressure, needle stroke variation and interaction with the internal cylinder flow, the individual injection pulses of this injection are adapted in such a manner that the best possible mixture distribution is achieved and no significant fuel deposition on the cylinder wall takes place. The needle opening duration during the individual pulses of the after-injection NE is set smaller than the needle opening duration of the main injection HE.

During the after-injection NE the needle stroke is varied, preferably being made progressively smaller. During this after-injection with variable needle stroke a constant fuel injection pressure is maintained which is preferably higher than the pressure during the pre-injection VE and lower than the pressure during the main injection HE. The pulsing during the after-injection NE is preferably such that the first fuel part-quantity of the after-injection is larger than the subsequent fuel part-quantity.

A second injection strategy is shown in Fig. 3 in which the internal combustion engine 1 is operated in a combined homogeneous/heterogeneous mode with a 5-pulse pre-injection VE with constant pulse duration and increasing injection pressure during pre-injection VE, a main injection HE at an increased injection pressure P_2 with the needle stroke h set to maximum, and a 5-pulse after-injection NE with constant pulse duration and decreasing injection pressure. Pulsing during the after-injection is preferably such that the first fuel part-quantity of the after-injection is the same or larger than the subsequent fuel part-quantity.

The pulsed pre-injection VE according to Fig. 3 takes place during the compression stroke in a crank angle range of approximately 80° CA to approximately 35°CA before TDC. It is effected in such a manner that the injection pressure increases at each pulse, i.e. during the pre-injection VE, in a common-rail injection system for example, a lower pressure prevails in the early injected part-quantities than in the subsequently injected part-quantities, the needle stroke h remaining constant during the pulsed pre-injection VE. The main injection then takes place at a higher injection pressure

P_2 in a range between TDC and approximately 30° CA after TDC. During the main injection HE the needle stroke h is set larger than in the pre-injection VE, the needle opening duration in the main injection HE being longer than in the pre-injection and the after-injection. During the after-injection NE the needle stroke h is kept at a constant value smaller than that of the main injection HE, while the injection pressure varies or decreases progressively. Different fuel pressure variation rates are set during the pre- and after-injections since during the pre- and the after-injections different combustion reactions take place in the combustion chamber 8, giving rise to different combustion chamber pressure and temperature curves.

The injection curve shown in Fig. 4 represents a particularly advantageous injection strategy. Here, combined homogeneous/heterogeneous operation is proposed with a 4-pulse pre-injection with increasing pulse duration at constant injection pressure in which the nozzle needle 13a is kept at a low stroke setting. In addition there is a main injection HE at a high injection pressure P_2 and with the needle stroke h set to maximum, and an after-injection NE with decreasing pulse duration at constant injection pressure P_3. Pulsing during the after-injection is preferably such that the first fuel part-quantity of the after-injection is larger than the subsequent fuel part-quantity.

This injection system enables different needle strokes to be set during a divided or pulsed injection process so that the part-quantity injected can be varied as necessary. Optionally however, the pulsing shown in Fig. 5 can be replaced by a block injection with a stroke setting limited in a defined

manner, for example by means of a piezo actuator. This has advantages over pulsing in terms of quantity constancy and nozzle wear.

In the case of purely conventional lean combustion without after-injection, the pre-injection VE can alternatively be carried out in a range between 40° CA and TDC and the main injection HE then preferably begins in a range between 15° CA before and 15° CA after TDC. The two can be carried out as a block injection in such a manner that the intensity of the injection jets is greater. To meet the requirements for effective lean combustion, the injection pressure is then set to a maximum level.

In the injection strategies according to Figs. 2 to 5 described above, the injection pressure P_1 during the pre-injection and the injection pressure P_3 during the after-injection are preferably chosen such that the fuel injected is not deposited to any significant extent on the boundaries of the combustion chamber 8.

Fig. 6 shows a schematic view of an injection nozzle 13 of the blind-hole nozzle type, although a nozzle of the socket hole type would be equally appropriate. The injection nozzle 13 shown in Fig. 6 illustrates the effect of an unstable cavitating flow induced in a nozzle hole 21 of the injection nozzle 13 at a short needle stroke h of the nozzle needle 13a, i.e. with the injection nozzle 13 partially open, and the effect thus achieved on a spreading angle α_1 of the injection jet 17.

On the right-hand side of Fig. 6 the injection nozzle 13 is only partially open, resulting in a throttling in the nozzle needle seat 22. This throttling produces a turbulent or unstable cavitating flow in the nozzle hole 21, which results in a large spreading angle α_1 of the fuel jet 17. Compared with a fully open injection nozzle with the maximum stroke setting, as shown on the left-hand side of Fig. 6, the spreading angle α_1 produced by said unstable cavitating flow is larger than a spreading angle α_2 produced without such a flow. The unstable cavitating flow gives rise to marked fluctuations in the internal nozzle flow 23 which, as the fuel emerges from the nozzle hole 21, results in increased disruption of the fuel jet and so in a large spreading angle α_1.

The fuel jet with spreading angle α_1 spreads into the combustion chamber with intensive atomisation and therefore causes better homogenisation and rapid vaporisation of the fuel so that more fuel can be injected in a part-quantity of the pre-injection VE or the after-injection NE without appreciable wetting of the combustion chamber wall. With the injection nozzle 13 with the maximum stroke setting shown on the left-hand side of Fig. 6, on the other hand, a two-phase flow 24 is produced in the nozzle hole 21 on the left-hand side, resulting in conventional disintegration of the fuel. Compared with a partially open injection nozzle, the spreading angle α_2 is smaller than the spreading angle α_1.

Selected adjustment of a desired throttle effect in the seating of the nozzle needle can be assisted by a suitable design, for example a 2-spring holder on the injection nozzle can cause the nozzle needle to remain at a stroke setting

between the completely closed and the fully open positions. Alternatively, such a setting can be realised with a nozzle needle directly controlled by a piezo control element.

To produce a spreading angle α_1 as large as possible with a partially open multi-hole injection nozzle, the nozzle should preferably be controlled such that the effective flow cross-section in the needle seating is preferably approximately 0.8 to 1.2 times the effective flow cross-section of the sum of all the cross-sections of the injection holes.

With the aforementioned injection strategies as illustrated in Figs. 2 to 5, it is also expedient to produce a spiralling motion that can be actuated and varied in the combustion chamber 8 of the internal combustion engine 1 so that a mixing cloud of an injected part-quantity is maintained during both the pre-injection VE and the after-injection NE by an appropriate spiralling movement of the charge in the combustion chamber and at the same time the jet penetration depth is reduced. The jet lobe or mixing cloud of an injection pulse is twisted so far by the spiral flow that during a subsequent injection pulse the newly formed jet lobes do not penetrate into the mixing cloud of the previous injected part-quantity. This reduces local over-enrichments and jet penetration depths so that, in particular, fewer soot particles are formed.

According to the invention the total quantity injected during the pre-injection VE, particularly when applying the above-mentioned injection strategies, is approximately 20% to 50% of the main injection quantity in the lower load range, i.e. up to 70% load, and approximately 10% to 30% of the main

injection quantity in the upper load range, i.e. from 70% to full load. This quantity is chosen such that knocking combustion is reliably prevented. This homogenised fuel fraction then burns almost free of soot and NO_x, but already produces a considerable proportion of the CO emission required from NO_x reduction in the NO_x storage catalyser and provides a significant fraction for reducing the air ratio.

It is also conceivable to do without the prior homogeneous combustion, in particular in a rich combustion mode, and to begin the main injection even earlier in a range between 20° CA and 5° CA before TDC. In this case, during after-injection in the rich mode the injection pressure of the individual fuel part-quantities varies since the gas density in the combustion chamber decreases continuously. Accordingly, the fuel injection pressure is also reduced correspondingly in steps or continuously. In this case the total quantity injected during the main injection HE is chosen such that, in combination with the subsequently injected fuel of the after-injection NE, the torque produced neither exceeds nor falls below the level achieved by conventional lean combustion. Limitation of the shift of the main injection HE to earlier timing in turn determines the maximum permissible peak pressure and the maximum permissible pressure increase in the cylinder. The rise or fall of the torque during rich operation above or below the value during lean operation is prevented by adapting the start of injection and the injection quantity of the main injection HE.

According to the invention the timing of the injections and the division of the individual part-quantities are varied as a function of the compression ratio of the engine. The values

given here are particularly suitable for a compression ratio of $\varepsilon=16$. At higher compression ratios, owing to the earlier start of the homogeneous combustion ignition when the compression is higher, the actuation duration for the injection timing of the homogeneous quantity is shifted to earlier by an appropriate number of crank angle degrees. Analogously, if the compression ratio is lower the beginning of the injection of the homogeneous quantity is shifted to later by a number of crank angle degrees. The same also applies for different choices of intake air temperatures. Measures that reduce the intake air temperature enable the beginning of the homogeneous quantity injection to be later. Measures that increase the intake air temperature entail a shift of the beginning of the homogeneous quantity injection to an earlier time.

DaimlerChrysler AG

Aifan
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Claims

1. Method for operating an internal combustion engine (1) with self-ignition, in which:
   - fuel is injected into a combustion chamber (8) in the form of a plurality of fuel jets (17) by means of an injection nozzle (13) with injection holes (21) comprising a nozzle needle (13a),
   - during an injection process part of the fuel is injected as a main injection (HE) and
   - at a later point after the main injection (HE) a quantity of fuel is injected as a pulsed after-injection (NE),

   characterised in that
   - the after-injection (NE) is injected in part-quantities pulsed in such manner that the said fuel part-quantities of the after-injection (NE) are of different sizes.

2. Method according to Claim 1,
   characterised in that
   during the pulsed after-injection (NE) a stroke of the nozzle needle (13a) of the injection nozzle (13) and/or a fuel injection pressure are adjusted in such manner that when each part-quantity of the after-injection (NE) is injected into the combustion chamber (8) the range of the respective fuel jet in the combustion chamber is limited

such that said range is smaller than the distance to a combustion chamber boundary.

3. Method according to Claim 1 or 2,
characterised in that
a first fuel part-quantity of the after-injection (NE) is larger than a subsequent fuel quantity of the after-injection (NE).

4. Method according to any of the preceding claims,
characterised in that
the after-injection (NE) is effected into the combustion chamber (8) at a lower injection pressure than the pressure of the main injection (HE).

5. Method according to any of the preceding claims,
characterised in that
the main injection (HE) begins in a crankshaft angle range of 10° CA before top-dead-centre (TDC) to 20° CA after top-dead-centre (TDC).

6. Method according to any of the preceding claims,
characterised in that
the after-injection (NE) begins in a crankshaft angle range of 30° CA to 100° CA after the end of the main injection (HE).

7. Method according to any of the preceding claims,
characterised in that
the after-injection (NE) takes place in two to eight pulses during an expansion stroke in a crankshaft angle range of 20° CA to 150° CA after top-dead-centre (TDC).

8. Method according to any of the preceding claims, **characterised in that** part of the fuel is injected as a pulsed pre-injection (VE) at an injection pressure lower than or equal to the pressure of the main injection (HE).

9. Method according to any of the preceding claims, **characterised in that** the pre-injection (VE) is effected in a crankshaft angle range of 140° CA to 60° CA before top-dead-centre (TDC).

10. Method according to any of the preceding claims, **characterised in that** the main injection (HE) is effected in a crankshaft angle range of 5° CA to 30° CA after an ignition time of the pre-injection (VE) in the combustion chamber (8).

11. Method according to any of the preceding claims, **characterised in that** the quantity of fuel used for the pre-injection (VE) in a lower and middle load range amounts to approximately 20% to 50% of the fuel quantity of the main injection (HE), and in an upper load range or at full load to approximately 10% to 30% of the fuel quantity of the main injection (HE).

12. Method according to any of the preceding claims, **characterised in that** during the after-injection (NE) and/or the pre-injection (VE) a fuel cloud of a fuel jet (17) produced during an injection pulse is displaced or moved laterally by virtue

of a spiralling movement that takes place in the combustion chamber (8).

13. Method according to any of the preceding claims,
characterised in that
the stroke of the nozzle needle (13a) of the injection nozzle is adjusted such that an unstable, cavitating flow is produced in the injection holes (21) of the injection nozzle (13).

14. Method according to any of the preceding claims,
characterised in that
the stroke of the nozzle needle (13a) of the injection nozzle (13) is varied such that within the injection nozzle (13) an effective flow cross-section between the nozzle needle (13a) and a nozzle needle seat (22) is approximately 0.8 to 1.2 times the effective flow cross-section of the sum of all the injection holes.

15. Injection nozzle for implementing the method according to any of Claims 1 to 14 which comprises an inwardly opening nozzle needle (13a) and a plurality of injection holes (21),
characterised in that
an injection hole cone angle of between 80° and 140° can be set between the injected fuel jets (17).

16. Injection nozzle according to Claim 15,
characterised in that
the stroke of the nozzle needle (13a) of the injection nozzle (13) can be set such that within the injection nozzle (13) an effective flow cross-section between the

nozzle needle (13a) and a nozzle needle seat (22) is approximately 0.8 to 1.2 times the effective flow cross-section of the sum of all the injection holes.

17. Injection nozzle according to Claim 16,
characterised in that
the stroke of the nozzle needle (13a) can be adjusted by means of a double spring holder, a piezo-controlled nozzle needle or a coaxial vario-nozzle.

DaimlerChrysler AG

Aifan
30.06.03

Abstract

The invention is based on a method for operating an internal combustion engine in which fuel is injected by means of an injection nozzle with a plurality of injection holes directly into a combustion chamber as main and after-injection and where appropriate pre-injection processes, the pre- and after-injections preferably being pulsed. In order to minimise wetting of the combustion chamber walls, during the after-injection the fuel part-quantities and a stroke of the nozzle needle of the injection nozzle are adjusted in such a manner that when each part-quantity of the after-injection is injected into the combustion chamber the range of the respective fuel jet in the combustion chamber is limited such that said range is smaller than the distance to a combustion chamber boundary.

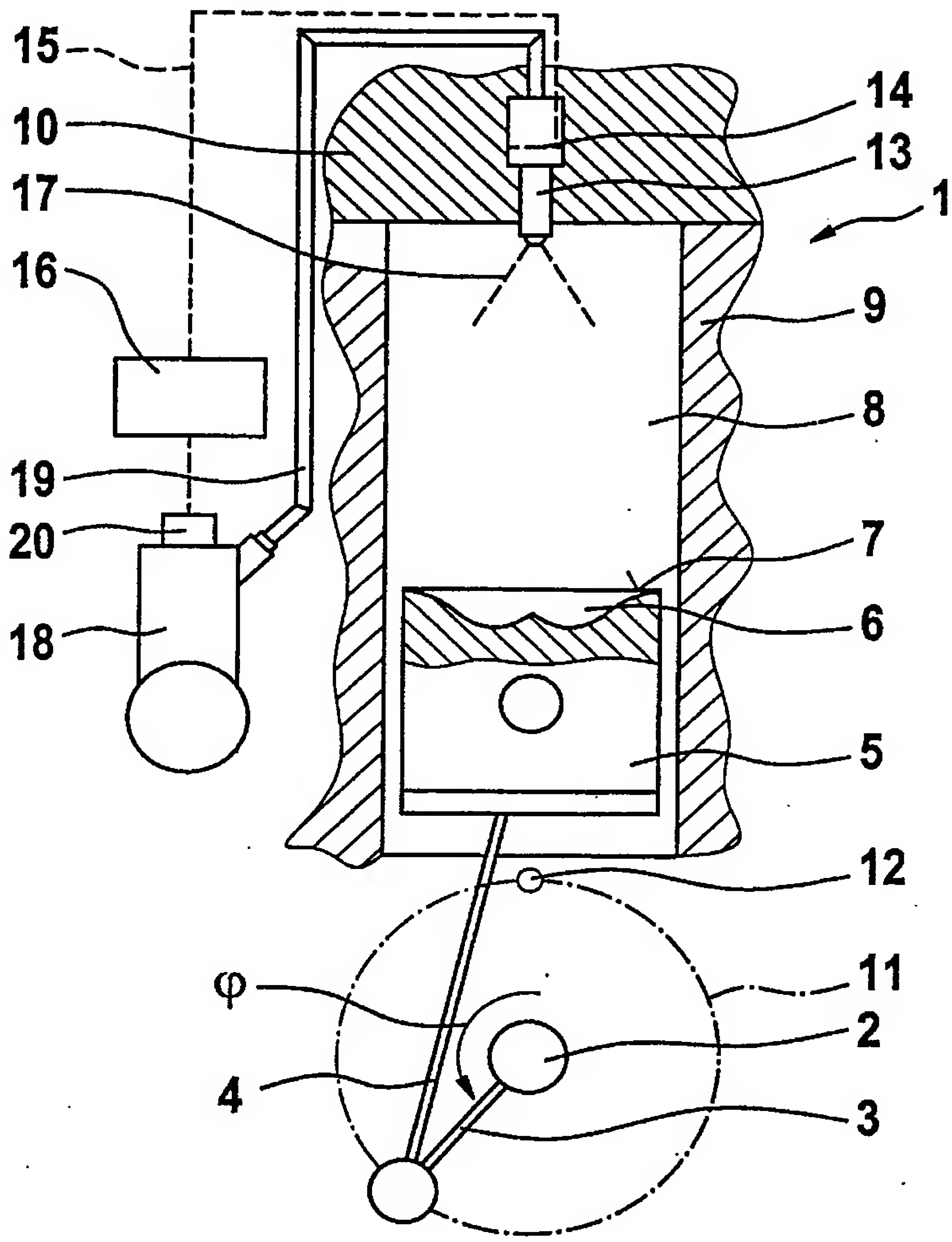

Fig. 1

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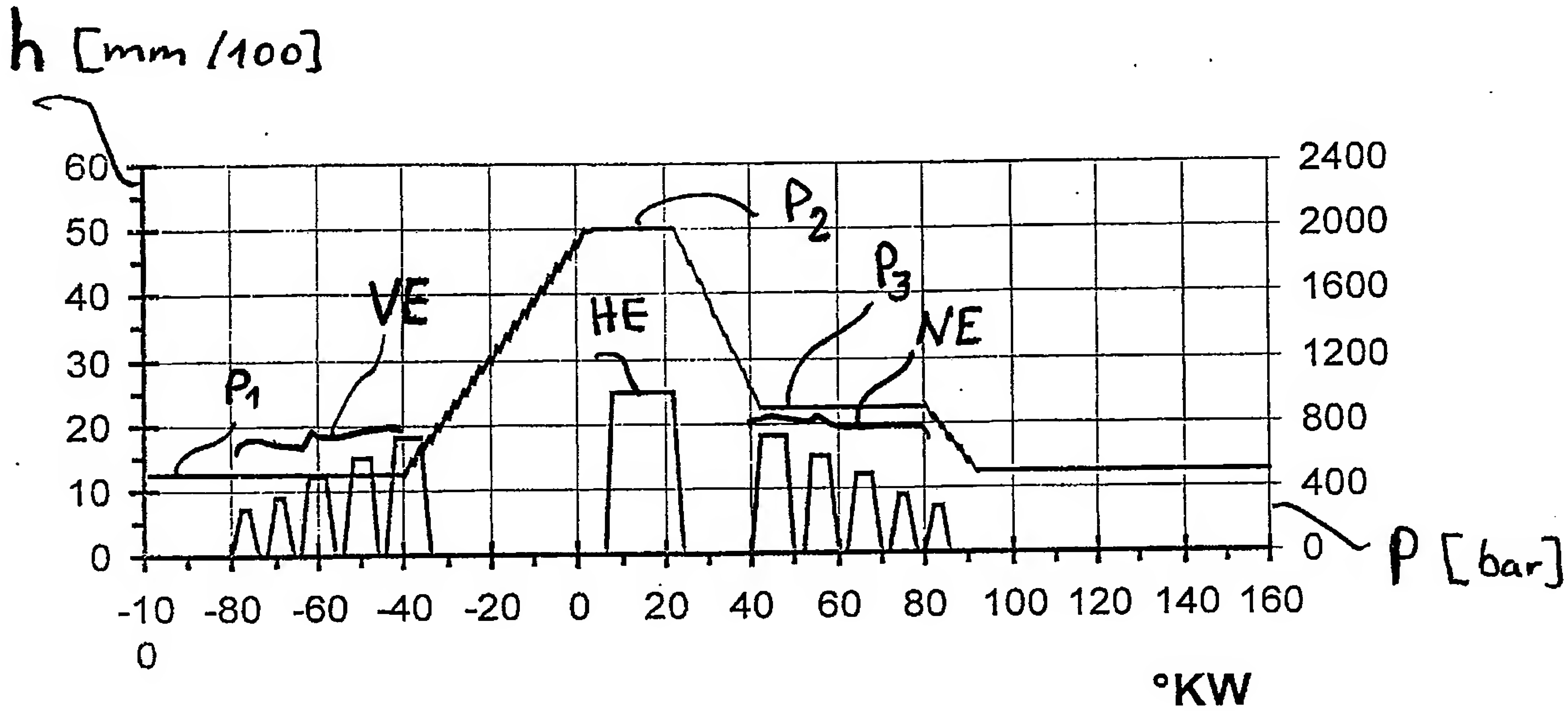


Fig. 2

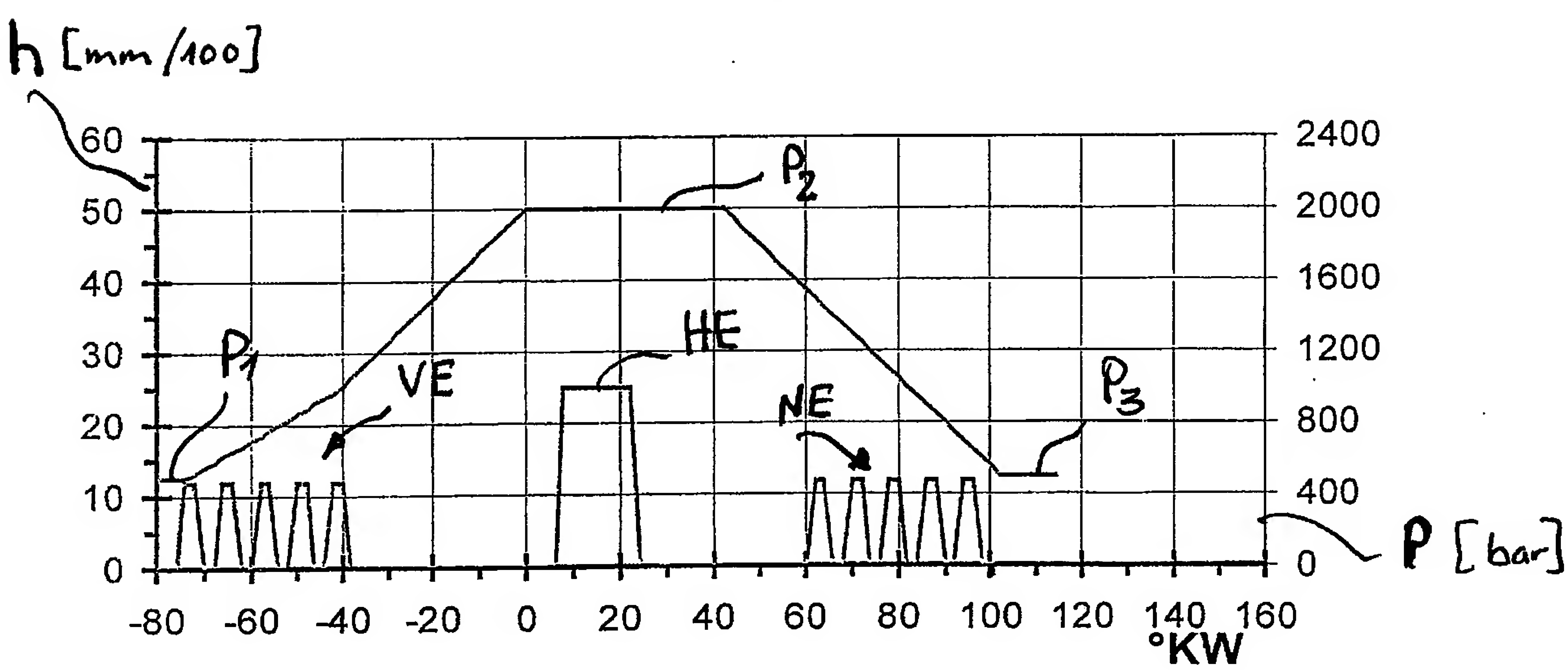
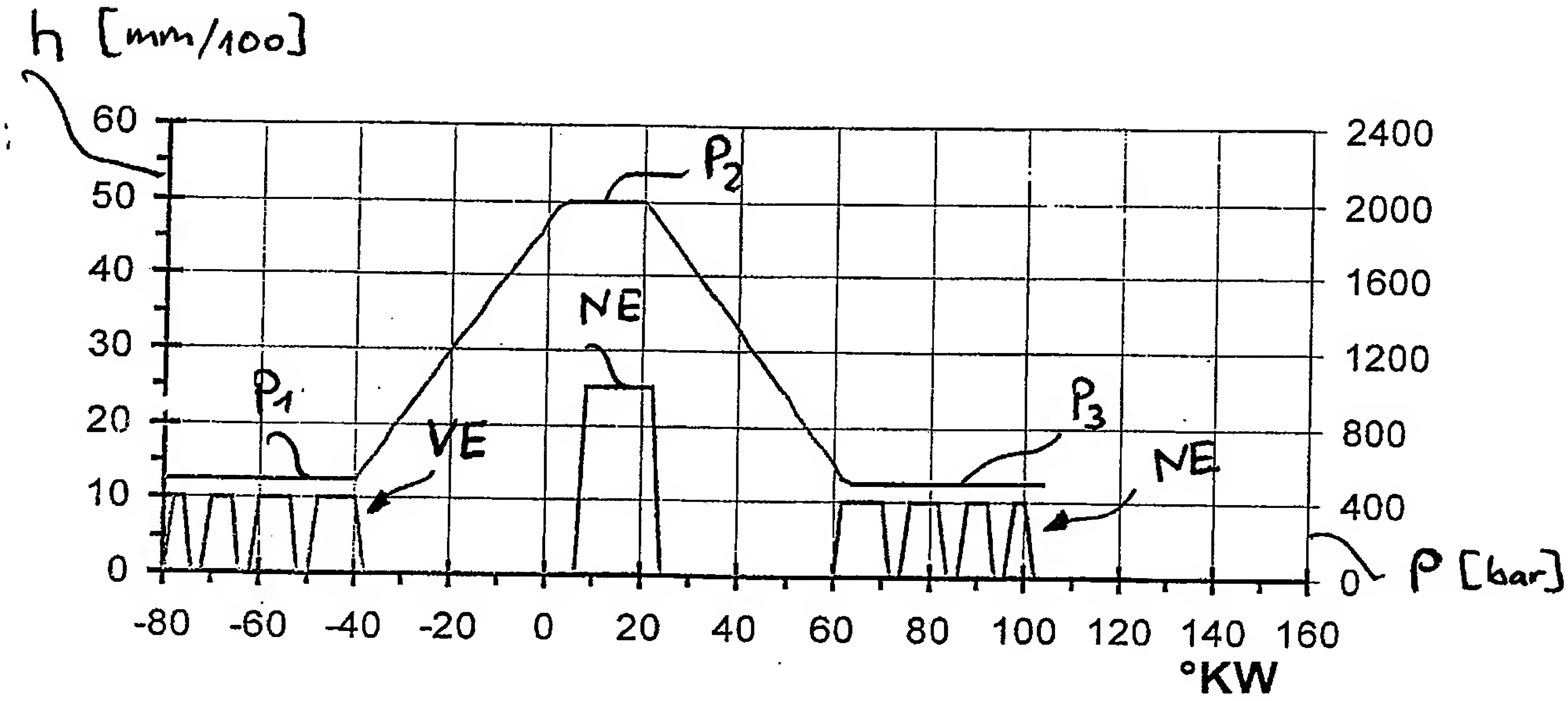


Fig. 3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120
140
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P1
P2
P3
VE
NE
NE

Fig. 4

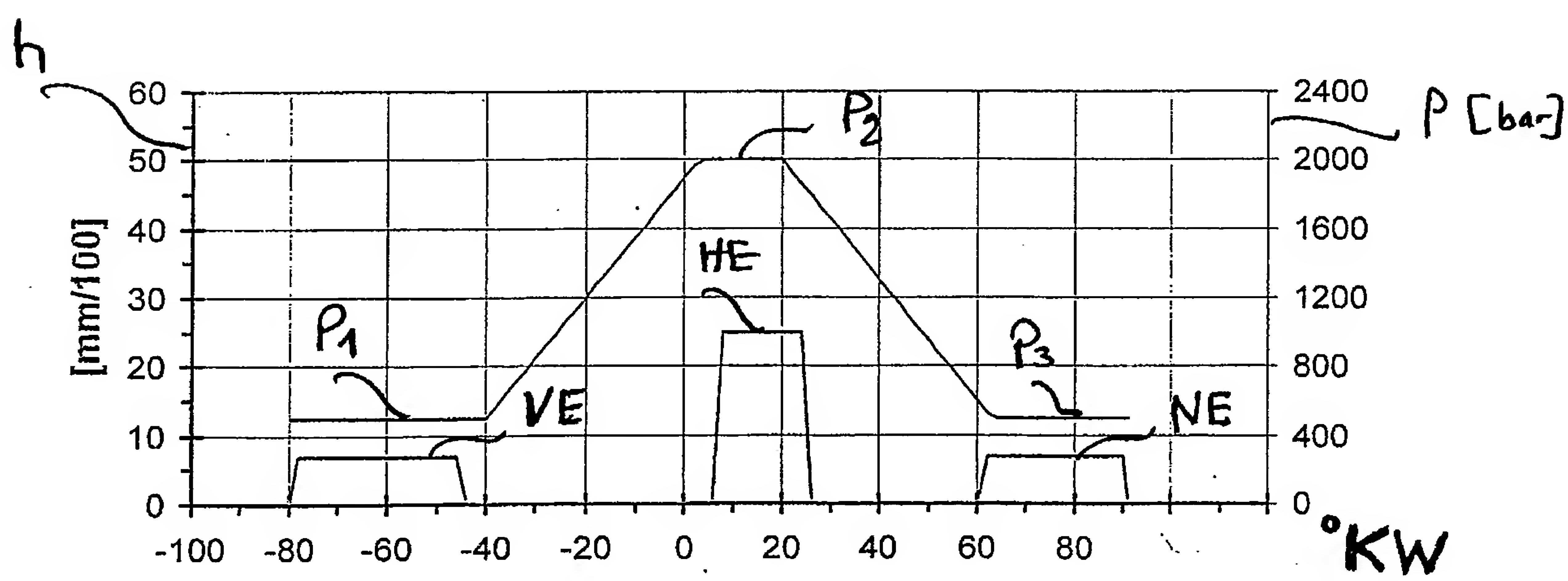
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Fig. 5

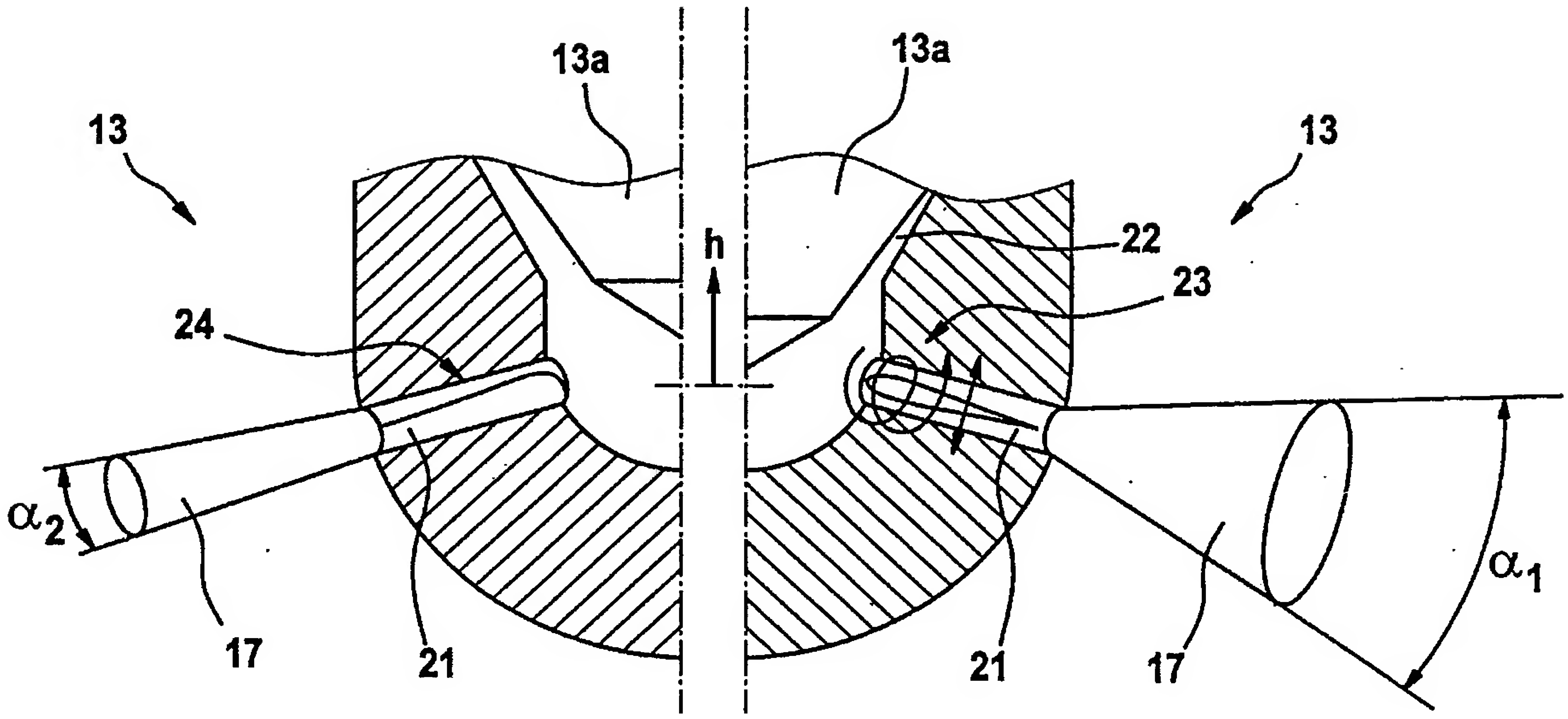

Fig. 6

DaimlerChrysler AG

30.06.2003

Zusammenfassung

Die Erfindung geht von einem Verfahren zum Betrieb einer Brennkraftmaschine aus, bei der Kraftstoff mittels einer Einspritzdüse mit mehreren Einspritzbohrungen direkt in einen Brennraum als Haupt- und Nacheinspritzung und gegebenenfalls als Voreinspritzung einspritzt wird, wobei vorzugsweise die Vor- und die Nacheinspritzung getaktet vorgenommen werden. Um die Benetzung der Brennraumwände zu minimieren, werden während der Nacheinspritzung die Kraftstoffteilmengen sowie ein Hub der Düsennadel der Einspritzdüse derart eingestellt, dass bei jeder in den Brennraum eingespritzten Teilmenge der Nacheinspritzung eine Reichweite des jeweiligen Kraftstoffstrahls im Brennraum derart begrenzt wird, dass die Reichweite kleiner als eine Entfernung bis zu einer Brennraumbegrenzung ist.